OIL SHALE RD&D PROGRAM OVERVIEW

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The largest untapped fossil fuel resource in the United States is the oil bearing shales in the western part of the country and the black, gas bearing shales in the east. The oil shale resource concentrated in three western states is estimated to be equivalent to more than two trillion barrels of crude oil. Associated with the western oil shales of Colorado are huge amounts of saline minerals capable of providing a major domestic source of commercial alumina and supplies of other commercial saline minerals which may be produced with shale oil. Due to the critical shortage of new energy supplies, particularly liquid fuels, it appears that development of shale oil and other synthetic fuels will become a necessary reality.

Since the earliest commercial interest more than 100 years ago, the history of oil shale has been one of ups-and-downs. In almost cyclical fashion, the shale industry has appeared to be on the verge of expanding rapidly, economics have appeared potentially viable, and the problems have seemed minimal. But then, a combination of factors, such as jumps in construction costs, the requirement for new environmental data, or the discovery of new conventional oil resources, have led to delays and in some cases, to pullouts by companies.

The Department of Energy (DOE) has established a research, development, and demonstration (R,D&D) program for encouraging the development of the country's oil shale resource at a commercial scale to help in the mitigation of the present and future energy demands. The aim of the Oil Shale Program is to stimulate the commercial production of shale oil by eliminating technical and environmental barriers. This paper provides an overview of the DOE Oil Shale R,D&D Program, addressing its essential elements.

Program Goal and Objectives

The Department of Energy's primary oil shale goal, as indicated below, is to foster the development of a commercial oil shale industry. In concert with this goal, the objectives of the DOE Oil Shale Program are to assist in the development of this industry through R,D&D, financial incentives, and the mitigation of institutional barriers, but not to mandate the choice of technology or markets to be served.

Program Goal

- To foster the development of a commercial oil shale industry.

Program Objectives

- To provide financial incentives to the private sector to encourage the construction of pioneer demonstration plants.

- o To mitigate institutional barriers to commercial oil shale development.

- o To provide, through an integrated technology base program, technical, economic, and environmental information to the private sector which will enhance its capability to build a shale oil industry.

- o To optimize oil shale processes or develop new oil shale concepts to ensure the most efficient and cost effective utilization of the nation's oil shale resource.

- o To obtain environmental data and develop environmental protection systems to ensure that the oil shale resource is developed in the most environmentally acceptable manner.

The analysis of commercialization incentives and mitigation of institutional barriers is the responsibility of the Assistant Secretary for Resource Applications. R,D&D activities are the responsibility of the Assistant Secretary for Fossil Energy, although the lead for environmental planning rests with the Assistant Secretary for Environment.

PROGRAM STRATEGY

In essence, the DOE program goal is to develop the technology necessary for the production of oil shale on a commercial basis and in an environmentally acceptable manner. The DOE strategy to accomplish this end is comprised of two major activity elements:

- o Research and Development

- o Commercial Development and Demonstration Support

Through the existence of these parallel activities, the DOE Oil Shale R,D&D Program focuses near term research and development (R&D) on supporting industrial development while maintaining an adequate level of more advanced R&D attuned to future needs. The technology developments that will result by achieving the program's objectives will be made available to the oil shale industrial community. Their participation in DOE sponsored demonstrations is encouraged as means of maintaining the technological alignment of the R,D&D Program with the needs of industry. These demonstration activities and direct financial incentives involve the DOE Program in the industrial decision process and facilitate oil shale industry growth. Information and experience gained through the construction and operation of any facilities resulting from these industry supportive activities will be used in assisting to define future R&D requirements which may be satisfied directly by the private sector through the program.

The Program's R&D activity elements are structured to parallel and complement activities that industrial developers would need to perform when establishing a commercial oil shale operation. The initial activities of a developer

include tasks to characterize the resource under consideration and site planning for resource development. Following this, the developer needs to consider the potential physical environment and socioeconomic impacts before committing to a proposed project. Oil shale resource development and extraction entail site preparation, mining (except for true in situ technologies), and rubbling the in situ retort in preparation for in place combustion or transporting the mined oil shale to a surface retort. Retorting would then be undertaken, after which the shale oil would be upgraded and refined. At each point in this sequence, the Oil Shale Program will develop enhanced technology to establish a potential developer's effectiveness.

KEY TECHNICAL AND ENVIRONMENTAL NEEDS IN R,D&D

Technical

The Oil Shale R,D&D Program is directed toward developing a greater understanding of the oil shale resource and perfecting effective means for the recovery of shale oil and associated mineral products. Program activities are directed toward the solution of key technical and environmental needs representing significant barriers to commercial oil shale development. Based on a review of technology required for oil shale development, the following Key Technical Needs have been identified as those that should receive the highest priority in the R,D&D Program:

- Efficient Oil Shale Rock Breakage and Retort Bed Preparation Techniques,
- Surface Retort Scaleup and Development,
- Development of Retort Diagnostics and Instrumentation,
- Development of Retort Control Procedures,
- Systems Engineering Methods for Total Oil Shale Process Development,
- Efficient and Effective Oil Shale Mining Systems,
- Advanced Shaft Sinking Technology,
- Shale Oil Upgrading Technology,
- Chemical Kinetics of the Total Pyrolysis Process,
- Understanding Retorting Mechanisms and Developing a Prediction Capability, and
- Development of Alternative Retorting Procedures.

Rock Breakage and Retort Bed Preparation. Efficient recovery of oil from shale depends critically upon having a bed of oil shale rubble that is relatively uniform, both in particle size and void fraction. Mining and rubbling methods must be developed to assure optimal uniformity. Otherwise sweep efficiency will be poor, and significant amounts of oil shale rubble will not be retorted.

It is expected that the R,D&D effort will result in the development of technology for breaking oil shale for mining and preparing rubble beds such that efficient and productive shale extraction and modified in situ retorting can be accomplished. Retorts will be designed and constructed which meet the processing requirements for particle size distribution, uniform permeability, uniform void distribution, and bounding of the fractured region.

Surface Retort Scaleup and Development. Currently, the most practical method of recovering shale oil is to mine the shale, crush it, and then retort it on the surface. Even with the employment of modified in situ technologies, some combination of in situ processing with surface retorting of the mined fraction is expected to be utilized. Surface retorting is the most proven technology for extraction of shale oil. However, the technology has been demonstrated only at pilot scale. Therefore, an increasing government effort is needed to advance surface retorting to a commercial scale. The DOE now is working toward the cooperative development of a full scale, surface module demonstration plant. The objective of this program is to stimulate the development of an oil shale industry by demonstrating the engineering, economic, and environmental feasibility of a surface retorting process at a unit scale considered necessary to provide commercial feasibility.

Retort Diagnosis and Instrumentation. The development of control instrumentation and methods for in situ retorting is important for determining retort performance and yield efficiency. The effort of the RD&D program will result in the design of thermal sensors, gas sampling devices, pressure probes, remote sensing devices, strain and displacement gauges, and health and safety monitoring equipment. This equipment will be designed and then tested and modified through use in several field tests.

Retort Control Procedures. The development of retort control and operating procedures is crucial to the success of both in situ and modified in situ retorting of oil shale. The R,D&D effort will establish a set of baseline operating plans from data collected from laboratory experiments, field tests and the outputs of predictive models. From the data collected, an evaluation will be made on the effects of intermittent air flows, liquid water additions, and other control parameters. The result of this effort will be a retort operating plan that maximizes retorting rate and yield while controlling temperature and burn front symmetry.

Systems Engineering. A systematic procedure for resource identification and characterization and for determination of appropriate recovery processes is needed to assure efficient and effective use of all domestic oil shale resources. The need related objectives of the R,D&D program are: (1) to develop and utilize methods for the planning of oil shale development by matching oil shale resources with appropriate recovery processes; (2) to develop planning tools (e.g., equipment selection criteria, production models, economic models) which will aid in the design and analysis of efficient shale oil production facilities; and (3) to determine the overall economics for the recovery of energy products from oil shale by the alternative processes.

Oil Shale Mining Systems. Equipment and methods now used for coal and hard rock mining are well developed but are not always applicable to the demands of oil shale mining. Research and development is needed to meet the particular requirements of the oil shale industry. The objective of the R,D&D program is to develop technology and equipment for high volume, cost effective, underground and surface mining methods for extracting oil shale for subsequent surface and modified in situ processing.

Shaft Sinking Technology. The development of shaft sinking systems is crucial for the large scale commercial utilization of oil shale. The R,D&D effort will carefully examine the current state of the art in shaft/slope development. A comprehensive research and development plan will be established that attacks all the major deficiencies in the current state of the art for accessing oil shale resources. Access development system concepts will be defined after a series of tasks which examine cutting and drilling methods, water/ground control, and large scale drilling. The expected result of this effort will be the development of techniques for efficient, safe, and environmentally acceptable shaft sinking.

Shale Oil Upgrading Technology. Crude shale oils generally contain greater amounts of certain elements and compounds that are not characteristic of conventional crude oils. These elements and compounds cause shale oils to exhibit properties that cause problems in storage, transportation and refining. The technology exists to convert and upgrade shale oils to products which can be processed in conventional ways, but it is necessary to determine which process schemes are most effective and economical. The R,D&D program will examine the production parameters of beneficiation, stabilization and preparation, denitrification, and alternative end-use options for liquid fuel products and heavy liquid fractions as they relate to the various retorting processes.

Chemical Kinetics. Several models have been developed which simulate the physical properties of oil shale retorting (e.g., shale composition, retorting rates, particle sizes, porosity distribution, etc.). For the models to accurately simulate retorting, they should include the details of the major chemical reactions in the system. The R,D&D program will develop the basic data on chemical kinetics needed to model the complex reactions taking place in retorting. Among these reactions are mineral decomposition, especially that of carbonates, which are large consumers of energy; reactions of char with steam and carbonate to produce valuable CO and hydrogen; degradation (loss) reactions of oil; gas phase reactions producing hydrogen and CO_2; gaseous sulfur evolution; etc. More work is needed on gas phase reactions, especially on water gas and water gas shift reactions, oil cracking stoichiometry of hydrocarbon combustion, and sulfur reactions in shale.

Retorting Mechanisms. Retorting technology is only crudely understood in lab and field retorts. Important operational problems include control of burn front, startup and sweep efficiency, effect of particle size distribution, inlet gas composition, especially steam and air mixtures, bed irregularities, flow rate, permeability changes during retorting, and temperature control. Program research will address key questions in the area of retorting mechanisms. A knowledge of the mechanisms taking place during retorting is

required to interpret results of experiments in pilot and field retorts to develop predictive models, and finally to suggest process modifications in order to optimize retort performance, expecially oil yields, and production rates. The development of retorting models will also be pursued as a means of understanding and predicting retort behavior.

Alternative Retorting Procedures. Oil shale retorting is approaching commercially viable levels of development. However, the technology is not sufficiently advanced to assure that optimally efficient and cost effective retorting methods are employed. The R,D&D program will examine alternative retorting processes with the objective of improving extraction efficiency and economics. Studies will include: (1) the use of oxygen (instead of air) plus steam to obtain high BTU outlet gas and reduce exit gas handling and cleanup; (2) the substitution of water mist for steam to improve heat balance; (3) determining retorting conditions to produce various optimum product mixes, e.g., maximum naphtha, minimum residuals, etc.; and (4) determining retorting conditions to produce minimum environmental effects (e.g., lowest sulfur in outlet gas, least soluble spent shale, etc.); (5) use of fluid beds to increase throughput, improve yield and lead to more favorable economics.

Environmental

The environmental research in the R,D&D Program represents a significant portion of the DOE's Environmental Development Plan. The overall objective of the Program's Environment Activity is to develop solutions to environmental problems associated with the process technologies involved in oil shale production. To achieve this objective, a series of Key Environmental Needs have also been established:

- Development of Environmentally Acceptable Retort Abandonment Strategy,
- Guidelines to Ensure Health and Safety of Workers and General Public,
- Development of Solid Waste Management Systems,
- Development of Water Treatment Systems,
- Development of an Emission Control Strategy,
- Mitigation of Ecological Impacts,
- Mitigation of Social and Economic Impacts,
- Development of Compliance Plans, and
- Development of Subsidence Control Procedures.

Development of Environmentally Acceptable Retort Abandonment Strategy. The spent shale remaining in underground retorts after product recovery contains salts and carbonaceous residues that can be leached by groundwater and thereby contaminate aquifers. In addition, some caving in from the weight of the overburden may occur resulting in subsidence at the surface.

The research related to this need will determine (1) the potential for groundwater intrusion, what materials are likely to be dissolved in groundwater, the permeability of the geologic media to the soluble components, the toxic properties of these components, and the persistence of any toxic components; and (2) the effectiveness of alternative measures for control of leaching and subsidence. The more general problem of subsidence in underground mines, the safety and ecological aspects, are dealt with in a separate area.

Guidelines to Ensure Health and Safety of Workers and General Public. Operations of an oil shale industry will introduce a new set of industrial working conditions and possible public health risks as a result of plant operations or product distribution. The research directed toward this need will examine the potential health and safety risks to workers and the general public. All aspects of the fuel cycle will be examined from the mine and retort to the refinery and end use of the shale oil products. Protective measures, whether they be through controls, process modification, or isolation of high risk areas, will be evaluated and effective measures will be applied.

Development of Solid Waste Management Systems. Surface processes produce extremely high volumes of solid waste in the form of spent shale. This research will evaluate methods of compacting and stabilizing spent shale and other solid wastes such as sludges and spent catalysts. The research will lead to the evaluation of alternatives for stabilizing and achieving self-sustaining ecosystems on the solid waste piles with minimum potential for water and wind erosion of toxic materials.

Development of Water Treatment Systems. In situ processes produce approximately one barrel of retort water contaminated with carbonaceous residues for each barrel of shale oil recovered. Surface processes also produce retort water but in lower quantities. Although current plans do not call for discharge of wastewater, it must be cleaned for reuse in the process and other uses, such as dust control and solid waste management. An objective of this research is to identify components in the wastewater that present either a health or environmental hazard with respect to the intended use of the water and to develop systems to remove these components. Another objective is to determine the consumptive water requirements of different oil shale processes.

Development of an Emissions Control Strategy. There are two major components to the emissions control need. One is directed toward determination of the emission control requirements based on the projected emission rates and composition of the emission streams. In the case of criteria or regulated pollutants, systems must be engineered to maintain ambient air quality within the region. In addition, modification of available technology and development of new systems may be required if risk analysis indicates that unique substances in the emission stream require removal.

The other component is directed toward estimation of the capacity of the region to accept industrial development--the regional carrying capacity--based on the meteorological characteristics of the region. More specific needs are (1) more accurate atmospheric models to predict the transport and dispersion of atmospheric pollutants, (2) determining rates at which pollutants are removed from the atmosphere, and (3) quantitative information on the effects of air pollutants on critical atmospheric processes related to undesirable effects, e.g., precipitation quality, decreased visibility, and local climate modification.

The research tasks that compose this segment of the plan will lead to the development of workable emission controls and estimates of effects of industrialization on regional air quality.

Mitigation of Ecological Impacts. Oil shale operations will cause much disruption of the surface environment through normal construction and operation activities--large amounts of solid waste stockpiles on the surface, water treatment operations, steam generation, mining, material handling, etc. The objectives of the ecological research, in addition to that which is an integral part of other activities such as the solid waste management system, will be to (1) evaluate overall effects of the operation on the ecological communities (plants, wildlife, fish) and (2) develop ecological test procedures that will be used by other parts of the program to evaluate systems performance with respect to ecological criteria. This work will be geared to the environmental impact approach described above.

Mitigation of Social and Community Economic Impacts. The social and community economic aspects of technological developments are among the most difficult to deal with. To a large extent, this is due to the fact that solutions involve institutional arrangements and legislative initiatives beyond the scope of most R&D operations. The problems do not lend themselves to controlled experiments that can be carried out in the field or laboratory. Installation of mitigating measures such as front-end financial support to communities for planning and development will be dealt with in DOE's industrialization plant. This R,D&D plan will focus on the social and economic issues for which solutions are not known and which therefore require additional research.

Methods for Controlling or Preventing Subsidence. Underground mines are always susceptible to subsidence, which presents a concern for safety and environmental disturbance, including aquifer disruption and changes in the surface land form. Some of the retort abandonment control measures will also act to prevent subsidence. The R&D conducted to satisfy this need will focus on general underground mining whether related to underground processes or surface retorting processes. It will be closely tied to the mining tasks and include analyses of safety, hydrological disruption, and changes in surface features. The research will focus primarily on prevention or planned, controlled subsidence.

Development of Compliance Plans. The R,D&D tasks, for environmental as well as the other three activities included in the Management Plan are carried out in conjunction with, or as part of, major field projects. These projects, which involve engineering and construction activities, must comply with Federal, state, and local standards, and in particular, with provisions of the National Environmental Policy Act (NEPA).

DOE prepares Environmental Assessments, and Environmental Impact Statements when appropriate, for those major field projects. Air, water, and other environmental monitoring, as required to demonstrate compliance with NEPA and applicable permits, is conducted as part of this need; that data is made available to other tasks for various analyses and decisions.

PROCESS SPECIFIC R,D&D

In addition to satisfying key needs which presently impede oil shale commercialization the Oil Shale R,D&D Program will simultaneously address the following processes.

Surface Processing. The DOE is pursuing a surface module demonstration program as described in PL 95-238. This program will result in both design and business proposals for the construction of a surface retort module. A decision to proceed with construction of designed modules on a cost shared basis will be made in late FY1980. Other research and development supporting surface retorting is mainly focused on mining and environmental effects with long term R&D directed to improving surface retorting processes.

In Situ Processing. The current near term emphasis of the Program's research activities is on developing and expanding in situ retorting process technology, with particular emphasis on modified in situ methods. This programmatic direction is based on the fact that in situ oil shale technology has not advanced to the point where it has been proven to be technically or economically feasible. Engineering analyses indicate that in situ processes have the potential to be more cost effective and less disruptive to the environment than surface retorting. Therefore, the program is focused on developing the necessary technical and environmental information from which an economic and environmentally acceptable in situ technology can be engineered.

In addition to this technology base program, the DOE is also sponsoring several major in situ oil shale field demonstration tests. The field demonstration test program and the technology based R&D programs are integrally related, in that field demonstration sites are often used as sites for R,D&D program efforts and information gained from the field tests is used to guide the

overall R,D&D program. Each of these projects has been evaluated to determine the program technology requirements that can be met by ongoing industry contracts and the other technology requirements that can be achieved through modification of the ongoing effort. In addition to providing valuable technology base information, it is anticipated that one or more of these projects could provide technical evidence of process feasibility. Use of existing projects to accomplish planned tasks will be maximized to reduce total program costs.

Novel Processing Techniques. In addition to the developmentally more advanced aboveground and in situ methods, research is being conducted into new and novel technologies for extraction and processing of oil shale products. Although not currently competitive for near term commercial development, these efforts are indicators of likely second generation advances in oil shale technology.

The novel technologies being developed are in two general categories.

- o Radio Frequency Heating
- o Hydrogen Retorting

PROGRAM OPERATING PLANS

The Oil Shale R,D&D Program is defined in two program plans presently in draft status: a Management and Strategic Plan which describes the R,D&D program management structure and the long term strategic aspects of the Department of Energy's program for achieving its technology objectives, and an Implementation Plan which details oil shale R,D&D activities over the next several years to the subactivity task level. In contrast to the Implementation Plan, the Management and Strategic Plan describes the Program's objectives as they will be attained by satisfying a series of technological needs, each of which may require the successful performance of one or more sets of tasks sometime in the future. Described are oil shale R,D&D activities for a multiyear period in terms of needs, with emphasis placed upon solving key technical and environmental needs inhibiting oil shale commercialization and developing an activity baseline for each of several candidate technologies to establish program direction, resource requirements, and expected accomplishment. Both plans serve as a basis for developing and justifying future budget requests over their respective periods.

Strategic Plan. The policy, management, organization, and long term aspects of the Oil Shale R,D&D Program, as directed toward satisfying its goal and objectives, are described in the Management and Strategic Plan. The discussion is in three parts, addressing planned program efforts concerned with:

- o Key Technical Need R,D&D
- o Key Environmental Need R,D&D
- o Process Specific R,D&D

These efforts are defined at the fundamental needs level, each R,D&D objective (a key need being one such objective) requiring the fulfillment of one or more of these fundamental needs before it is obtained. This is in contrast to the manner in which the Implementation Plan is defined, wherein needs are specified in terms of the detailed tasks required to satisfy them. Strategic plans are outlined in a plane higher than that used in the Implementation Plan. Another distinction between the two is in their planning time horizon. Strategic plans are defined over a long term period, generally about ten years, whereas the Implementation Plan concentrates on the near term period not exceeding five years. To show continuity between the two plans, the time span addressed in the Implementation Plan is also defined with the strategic plans and need identifiers uniquely assigned in the Implementation Plan are referenced in the strategic plans.

Implementation Plan. Short term plans are defined in the Implementation Plan in terms of the activities and tasks to be performed. Outlined within the Plan are the research tasks that will be performed during the next five year period to enhance and encourage commercial oil shale development. The R,D&D tasks are described with respect to major activity areas (resource characterization, environment, development and extraction, and processing and instrumentation). Component subactivities within each of these activities provides a framework for organizing tasks around specified technology areas. For each program task the performance periods are specified in conjunction with task deliverables and participating organizations. The Plan, conceived as a working document which is annually updated, thus serves as a basis for implementing the R,D&D Program by the various research and industry participants.